PROCEEDINGS OF SCIENCE

Belle: CPV with Kpipi/pipipi(rho pi)

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We report results on studies of *CP* violation in the three-body charmless decay $B^{\pm} \to K^{\pm}\pi^{\pm}\pi^{\mp}$ and $B^0 \to \pi^+\pi^-\pi^0(\rho^0\pi^0)$. We find evidence at the 3.9σ level for large direct *CP* violation in the decay $B^{\pm} \to \rho(770)^0 K^{\pm}$. This is the first evidence for *CP* violation in a charged meson decay. We also find evidence of $B^0 \to \rho^0\pi^0$ decay and perform the first measurement of the direct *CP* violating asymmetry in this mode. The measurements are based on a data sample that contains 386 million $B\overline{B}$ pairs collected with the Belle detector at the KEKB asymmetric-energy e^+e^- (3.5 on 8.0 GeV) collider. KEKB operates at the $\Upsilon(4S)$ resonance ($\sqrt{s} = 10.58$ GeV) with a peak luminosity that exceeds $1.5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$.

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1. Introduction

In decays of B mesons to two-body final states ($B \to K\pi$, $\pi\pi$, etc), direct CP violation (DCPV) can only be observed as a difference in B and $\overline{B}$ decay rates. In decays to three-body final states which are often dominated by quasi-two-body channels, DCPV can also manifest itself as a difference in relative phase between two quasi-two-body amplitudes that can be measured via amplitude (Dalitz) analysis. Although DCPV has been observed in decays of neutral K mesons [1] and recently in neutral B meson decays [2] no CP violation in decays of charged mesons has been found to date.

Recently, the time-dependent amplitude analysis of $B^0 \to \pi^+\pi^-\pi^0$ decays, which can be used to extract the Unitarity triangle angle ϕ_2, has been performed for the first time [3]. In these studies the $B^0 \to \rho^0\pi^0$ contribution is assumed to be small. However, improved evidence for this decay would suggest that a less simplified Dalitz-plot analysis is necessary. Further, $B^0 \to \rho^0\pi^0$ branching fraction along with its CP asymmetry are needed to complete the $B^{+/0} \to \rho\pi$ isospin pentagon for the isospin analysis method of extracting ϕ_2.

2. Data Sample & Event Selection

Analysis of DCPV in the three-body charmless $B^\pm \to K^\pm\pi^\pm\pi^\mp$ decay is performed by means of Dalitz analysis technique [4]. Measurements of $B^0 \to \rho^0\pi^0$ are performed in the ρ^0-dominated region of $B^0 \to \pi^+\pi^-\pi^0$ phase-space [5]. Both analyses are based on a data sample that contains 386 ± 5 million $B\overline{B}$ pairs, collected with the Belle detector at the KEKB collider. The presented measurements supersede the results reported in Ref. [6] and [7].

We identify B candidates with two kinematic variables: $\Delta E = (\sum_i \sqrt{c^2\mathbf{p}_i^2 + c^4 m_i^2}) - E^*_{\rm beam}$ and $M_{\rm bc} = \frac{1}{c^2}\sqrt{E^{*2}_{\rm beam} - c^2(\sum_i \mathbf{p}_i)^2}$, where the summation is over all particles from a B candidate; $\mathbf{p}_i$ and m_i are their c.m. three-momenta and masses, respectively. The dominant background to the charmless three-body decays comes from continuum events, $e^+e^- \to q\overline{q}$ ($q = u, d, s, c$). This type of background is mostly suppressed using variables that characterize the event topology. For the $B^0 \to \rho^0\pi^0$ mode, additional suppression is achieved through use of the Belle flavour tagging parameter r [8], which can be used as a measure of the confidence that the remaining particles in the event (other than $\pi^+\pi^-\pi^0$) originate from a flavour specific B meson decay.

Backgrounds from B decays are identified using large Monte Carlo (MC) simulated samples. Possible contributions to the $K^+\pi^+\pi^-$ / $\pi^+\pi^-\pi^0$ final state from charmed ($b \to c$) backgrounds are explicitly vetoed for decays $B \to Dh$ and $B \to J/\psi(\psi(2S))[\mu^+\mu^-]h$, where h stands for a charged pion or kaon, by applying requirements on the invariant mass of the appropriate two-particle combination. The remaining $b \to c$ combinatorial background is taken into account when fitting the data. The most significant background from charmless B decays to $B^\pm \to K^\pm\pi^\pm\pi^\mp$($B^0 \to \rho^0\pi^0$) originates from $B^+ \to \eta' K^+$, $B^+ \to \pi^+\pi^+\pi^-$ and $B^0 \to K^+\pi^-$ ($B^+ \to \rho^+\rho^0$, $B^+ \to \rho^+\pi^0$ and $B^+ \to \pi^+\pi^0$). These backgrounds cannot be removed and are included in the data fit. The $\Delta E(M_{\rm bc})$ distributions for $B^\pm \to K^\pm\pi^\pm\pi^\mp$and $B^0 \to \rho^0\pi^0$ candidates that pass all the selection requirements are shown in Fig. 1 (a) and Fig. 2 (a, b) respectively. A detailed description of the event selection and background suppression techniques used in $B^\pm \to K^\pm\pi^\pm\pi^\mp$and $B^0 \to \rho^0\pi^0$ analyses can be found in Ref. [4] and [5], respectively.

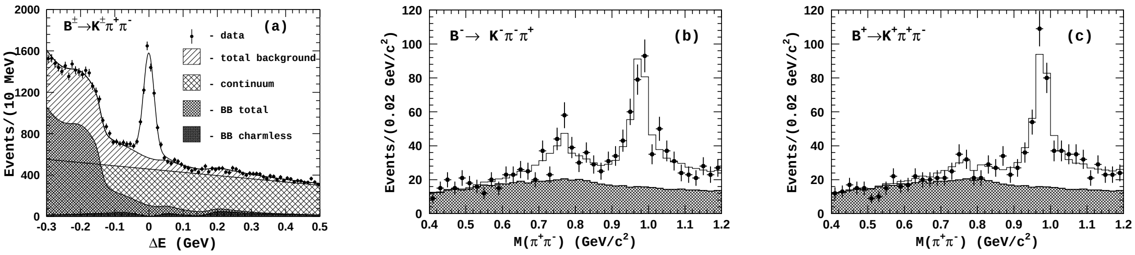

Figure 1: (a) ΔE distribution for $B^{\pm} \to K^{\pm}\pi^{\pm}\pi^{\mp}$ candidate events; (b), (c) $m_{\pi^+\pi^-}$ mass spectra for B^- and B^+ events. Points with error bars are data, the open histogram is the fit result and hatched histogram is the background component.

3. $B^{\pm} \to K^{\pm}\pi^{\pm}\pi^{\mp}$ Dalitz Analysis Results

Events in the B signal region defined as an ellipse around the $M_{\rm bc}$ and ΔE mean values are selected for the amplitude analysis. The $B^{\pm} \to K^{\pm}\pi^{\pm}\pi^{\mp}$signal was found to be well described by a coherent sum of $K^*(892)^0\pi^+$, $K_0^*(1430)^0\pi^+$, $\rho(770)^0K^+$, $f_0(980)K^+$, $f_X(1300)K^+$, $\chi_{c0}K^+$ quasi-two-body channels and a non-resonant amplitude [6]. In this analysis we modify the model by adding two more quasi-two-body channels, $f_2(1270)K^+$ and $\omega(782)K^+$, and change the parameterization of the $f_0(980)$ lineshape from a standard Breit-Wigner function to a coupled channel Breit-Wigner (Flatté parameterization). For the DCPV search, the amplitude for each quasi-two-body channel, $ae^{i\delta}$, is parameterized such that a plus (minus) sign is allocated to a B^+ (B^-) decay: $ae^{i\delta}(1 \pm be^{i\phi})$. With this parameterization, the CP violating asymmetry A_{CP} for a particular quasi-two-body channel can be calculated as $A_{CP}(f) = (N^- - N^+)/(N^- + N^+) = -(2b\cos\varphi)/(1+b^2)$.

To reduce the number of free fit parameters, we fit the data in two steps. First we fix all $b_i = 0$ (assume no CP violation) and determine the parameters of the $f_X(1300)$, $f_0(980)$ and the parameter of the non-resonant amplitude. We then repeat the fit to data with these parameters fixed, while b_i and φ_i are allowed to float. We assume no DCPV in $B^{\pm} \to \omega(782)K^{\pm}$ and the non-resonant amplitude; possible effects of these assumptions are considered as a part of the model uncertainty.

Table 1: Results of the best fit to $K^{\pm}\pi^{\pm}\pi^{\mp}$ events in the B signal region. The first quoted error is statistical and the second is the model dependent uncertainty. The quoted significance is statistical only, calculated as $\sqrt{-2\ln(\mathscr{L}_0/\mathscr{L}_{\rm max})}$, where $\mathscr{L}_{\rm max}$ and $\mathscr{L}_0$ denote the maximum likelihood with nominal fit and with the asymmetry fixed at zero, respectively.

Channel	b	φ (deg.)	A_{CP} (%)	Significance (σ)
$K^*(892)^0\pi^{\pm}$	$0.078 \pm 0.033^{+0.012}_{-0.003}$	$-18 \pm 44^{+5}_{-13}$	$-14.9 \pm 6.4^{+0.8}_{-0.8}$	2.6
$K_0(1430)^0\pi^{\pm}$	$0.069 \pm 0.031^{+0.010}_{-0.008}$	$-123 \pm 16^{+4}_{-5}$	$+7.5 \pm 3.8^{+2.0}_{-0.9}$	2.7
$\rho(770)^0K^{\pm}$	$0.28 \pm 0.11^{+0.07}_{-0.09}$	$-125 \pm 32^{+10}_{-85}$	$+30 \pm 11^{+11}_{-4}$	3.9
$f_0(980)K^{\pm}$	$0.30 \pm 0.19^{+0.05}_{-0.10}$	$-82 \pm 8^{+2}_{-2}$	$-7.7 \pm 6.5^{+4.1}_{-1.6}$	1.6
$f_2(1270)K^{\pm}$	$0.37 \pm 0.17^{+0.11}_{-0.03}$	$-24 \pm 29^{+14}_{-20}$	$-59 \pm 22^{+3}_{-3}$	2.7
$\chi_{c0}K^{\pm}$	$0.15 \pm 0.35^{+0.08}_{-0.07}$	$-77 \pm 94^{+154}_{-11}$	$-6.5 \pm 19.6^{+2.9}_{-1.4}$	0.7

Results of the final fit are given in Table 1. The only channel where the statistical significance of the CP asymmetry exceeds the 3σ level is $B^{\pm} \to \rho(770)^0K^{\pm}$. Figures 1 (b, c) show the $\pi^+\pi^-$ invariant mass distributions for the $\rho(770)^0 - f_0(980)$ mass region separately for B^- and B^+ events.

4. $B^0 \to \rho^0\pi^0$ Results

We measure the signal yield using an extended unbinned maximum-likelihood fit to the ΔE-$M_{\rm bc}$ distribution. We obtain 51^{+14}_{-13} signal events with a significance of 4.2σ including systematic uncertainties and measure the branching fraction to be $\mathscr{B}\left(\rho^0\pi^0\right) = \left(3.12^{+0.88}_{-0.82}(\text{stat})^{+0.60}_{-0.76}(\text{syst})\right) \times 10^{-6}$. In order to check that the signal candidates originate from $B^0 \to \rho^0\pi^0$ decays, we change the criteria on $m_{\pi^+\pi^-}$ and $\cos\theta^{\rho}_{\rm hel}$ in turn, and repeat fits to the ΔE-$M_{\rm bc}$ distribution. The yields obtained in each $m_{\pi^+\pi^-}$ and $\cos\theta^{\rho}_{\rm hel}$ bin are shown in Fig. 2 (c) and (d).

Having observed a significant $B^0 \to \rho^0\pi^0$ signal, we utilize the $B^0/\overline{B}{}^0$ separation provided by the flavour tagging to measure the *CP* asymmetry by defining the probability density function (PDF) as: $\mathscr{P}^i_{j,l} = \frac{1}{2}\left[1+q^i\cdot(A^{'}_{\rm CP})_{j,l}\right]P_{j,l}(M^i_{\rm bc},\Delta E^i)$ where q is the b-flavour charge [$q = +1\,(-1)$ when the tagging B meson is a B^0 ($\overline{B}{}^0$)], $P_{j,l}$ is the two dimensional PDF in ΔE and $M_{\rm bc}$, and $A^{'}_{\rm CP}$ is the effective charge asymmetry, such that $(A^{'}_{\rm CP})_{j,l} = (A_{\rm CP})_j(1-2\chi_d)(1-2w_l)$. Here, $(A_{\rm CP})_j$ are the charge asymmetries for the signal and the background components, χ_d is the time-integrated mixing parameter and w_l is the wrong-tag fraction. The only free $A_{\rm CP}$ parameter in the nominal fit, is that of our signal; the rest are fixed to be zero. We measure the direct *CP* asymmetry of $B^0 \to \rho^0\pi^0$ to be $A_{CP} = -0.49^{+0.67}_{-0.81}(\text{stat})^{+0.20}_{-0.24}(\text{syst})$. To illustrate the asymmetry, the results are shown separately for $\rho^0\pi^0$ candidate events tagged as B^0 and $\overline{B}{}^0$ in Fig. 2 (e, f).

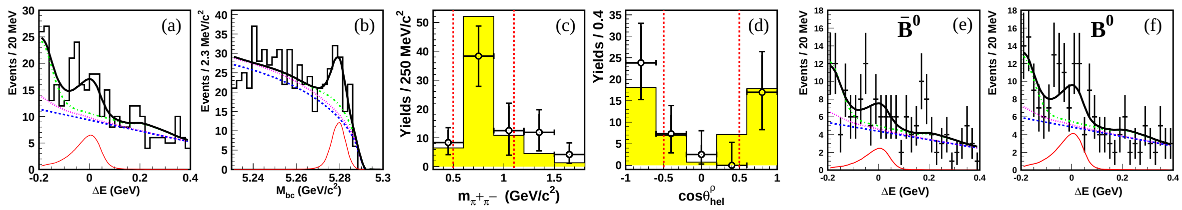

Figure 2: (a), (b) Distribution of $\Delta E(M_{\rm bc})$ in the signal region of $M_{\rm bc}(\Delta E)$. Projection of the fit result is shown as the thick solid curve; the thin solid line represents the signal component; the dashed, dotted and dash-dotted curves represent, respectively, the cumulative background components from continuum processes, $b \to c$ decays, and charmless B backgrounds. (c), (d) Distributions of fit yields in $m_{\pi^+\pi^-}$ and $\cos\theta^{\rho}_{\rm hel}$ variables for $\rho^0\pi^0$ candidate events. Points with error bars represent data fit results, and the histograms show signal MC expectation. (e) (f) ΔE distributions shown separately for events tagged as $\overline{B}{}^0/B^0$

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